# IMPACTS OF RECENT INVASIVE SPECIES ON NEARSHORE FISHES

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## Introduction

Invasive species have impacted Lake Michigan's fisheries for 70 years. The passage through the Welland Canal by sea lamprey, after it invaded Lake Ontario, led to its establishment in Lake Michigan where it was first seen in 1936 (Christie and Goddard 2003). A combination of overfishing and sea lamprey predation led to the extirpation of lake trout (Coble et al. 1990; Hansen 1999) and to the extirpation or extinction of several deepwater ciscoes endemic to the Great Lakes (Coon 1999). Alewives, probably through interference with reproduction, likely caused the decline in abundances of deepwater sculpins and yellow perch during the 1960s and may have delayed the recovery of burbot in Lake Michigan until the 1980s (Madenjian et al. 2002). From 1959 to 1999, the rate of new introductions into the Great Lakes has increased to more than one species per year

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(Grigorovich et al. 2003), resulting in the establishment of numerous invaders during the past 20 years. In this report, we focus on (1) the status of six recent invasive species during 2000-2004, (2) the identity of other species that could invade in the near future, (3) examples of their impacts on the nearshore fish community, and (4) the implications for fishery management.

# Status

## Spiny Water Flea

*Bythotrephes longimanus* was first recorded in Lake Michigan in 1986 (Evans 1988). Native to the Ponto-Caspian region of Europe, this predatory cladoceran has been implicated in the reduction of small-bodied daphnids since the 1980s (Lehman 1991). Although few regular estimates of lakewide densities are available, mean density of *Bythotrephes* averaged across eight sites was 570/m$^2$ in offshore waters during September 2000 (Pothoven et al. 2003). Except for being implicated in reduced diversity of the offshore *Daphnia* species complex (Lehman and Cáceres 1993), this invader has had little apparent impact on nearshore fishes.

## Zebra and Quagga Mussels

Zebra mussels were first documented in Lake Michigan in 1989 (Marsden 1992) and rapidly increased their population size in nearshore rocky habitats (Marsden 1992). Quagga mussels were first documented in Lake Ontario (May and Marsden 1992) and were present in Lake Michigan by 1997 (Nalepa et al. 2001). Although little quantitative monitoring of zebra mussels is conducted in Lake Michigan, an estimate of lakewide biomass is available from U.S. Geological Survey fall bottom-trawl assessments. Between 1999 and 2004, lakewide biomass of zebra and quagga mussels ranged from 14 kt (1,000s of metric tones) in 1999 to a peak of 43 kt in 2001 and returned to 14 kt in 2003 (Madenjian et al. 2005a). These lakewide estimates are likely conservative because trawls are not fished over the hard substrate on which zebra mussels prefer to attach (Fleischer et al. 2001; Coakley et al. 2002). Zebra mussel biomass was not separated from quagga mussel biomass in these trawl surveys, but observations suggest that the proportion of quagga mussels has been increasing in recent years.

## Round Goby

This invader was first reported from Lake Michigan in 1993 (Charlebois et al. 1997). Since then it has spread slowly through southern Lake Michigan and most likely was transported via commercial shipping to ports farther north in the lake (Mills et al. 1993; Jude 2001), where it has further spread northward and eastward (Clapp et al. 2001). As round gobies spread into the lake, assessment trawls documented their increased relative abundance. Trawling by both the Michigan Department of Natural Resources (DNR) at Grand Haven and by Ball State University (BSU) in Indiana waters first detected round gobies in 1997 (Michigan DNR) and 1998 (BSU). Catch rates rose by two orders of magnitude within two years and, since then, have generally remained at similarly high levels (Lauer et al. 2004).

## Fishhook Water Flea

*Cercopagis pengoi*, the fishhook water flea, was first recorded in Lake Michigan in 1999 (Charlebois et al. 2001). Like *Bythotrephes longimanus*, its relative, this invasive predatory cladoceran from the Ponto-Caspian region feeds on zooplankton. Unlike its relative, *Cercopagis* feeds primarily on smaller zooplankton, including rotifers, juvenile copepods, and small cladocerans (Vanderploeg et al. 2001; Benoit et al. 2002; Laxson et al. 2003). The abundance of this species, although variable, has trended upwards (Witt et al. 2005). Its impacts on the food web remain uncertain. Improved monitoring of its population dynamics and community impacts remains important to fully understand whether this invader will exert strong impacts on the nearshore food web.

## Ruffe

Ruffe, a Eurasian fish, was first documented in Lake Michigan at Little Bay de Noc in 2002. It was found there again in 2003 and 2004 and since has spread to Big Bay de Noc. In other targeted and routine sampling around the lake, no other populations of ruffe have been reported. It is unclear why this species has expanded relatively slowly after introduction into Lake Michigan. The pattern of slow spread observed in Lake Superior, about 200 miles in eight years from 1987 to 1994 (Gunderson et al. 1998), may result from the apparent negative relationship between ruffe abundance and system productivity (Ogle 1998). Ruffe may initially colonize a location via commercial shipping but, once established, do not aggressively immigrate into new areas. This behavior may provide a control method if ports are at risk.

### Species on the Doorstep

Other potential invaders could arrive during the next few years. Of special concern is the possibility that silver carp or bighead carp, collectively known as Asian carp, could enter Lake Michigan through the Chicago Sanitary and Ship Canal (CSSC), the live food trade, or by other means. A permanent electric barrier is being constructed in the CSSC to deter movement across this artificial connection between the Mississippi River and Great Lakes drainages. Similarly, efforts among U.S. and Canadian agencies and legislative bodies are seeking to eliminate the trade in live Asian carp.

The northern snakehead is another potential invader. This species escaped into the Potomac River basin, most likely from aquarium releases. Specimens have been collected by the Wisconsin DNR and Michigan DNR on the non-Great Lakes waters of these states. One snakehead was collected by an angler while fishing in a Chicago harbor in October 2004. Based on an intensive sampling effort in the harbor, best estimates suggest that this snakehead was released from an aquarium and is not part of an established population. However, additional monitoring of Chicago harbors will continue to provide critical early warning.

Kolar and Lodge (2002) recently developed quantitative models of invasability characteristics of fishes from the Ponto-Caspian region. Based on their models, other fishes that could rise to pest status if they do establish in the Great Lakes include tyulka, Eurasian minnow, Black Sea silverside, European perch, and monkey goby.

## Direct and Indirect Impacts

Invasive species affect Lake Michigan fishes both directly and indirectly. We illustrate direct impacts using round goby as an example and indirect impacts using dreissenid mussels, because few effects of the other species are known.

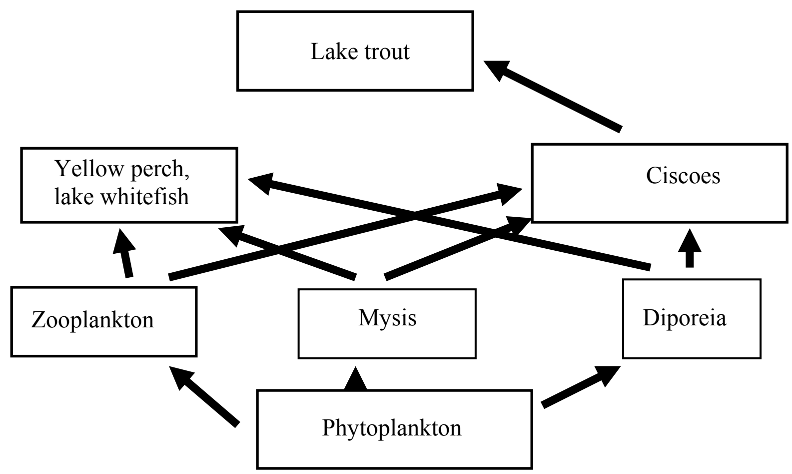
Round gobies can exert both positive and negative impacts on the nearshore fish community. They serve as prey for nearshore fishes, such as yellow perch (Truemper and Lauer 2005) and smallmouth bass, whose growth rates at age 0 have increased in Lake Erie since round gobies became abundant (Steinhart et al. 2004). Similarly, lake whitefish, lake trout, burbot, brown trout, and coho salmon have been reported to consume round gobies. Although consumption of round gobies could be positive for predators, negative impacts of consumption of round gobies are also likely. Specifically, because round gobies >50 mm in length consume primarily dreissenid mussels, biomagnification of toxic substances, such as polychlorinated biphenyls and polychlorinated naphthalenes, through the food web is likely (Hanari et al. 2004).

Round gobies have essentially eliminated important nearshore benthic fishes, such as mottled sculpin and johnny darter (Janssen and Jude 2001; Lauer et al. 2004). The mechanisms behind this displacement include agonistic interactions for refuges (Dubs and Corkum 1996) and egg predation by round gobies on mottled sculpin nests (Janssen and Jude 2001). Because round gobies are voracious egg predators, they may negatively affect restoration efforts for native fishes by eating their eggs and fry (e.g., Chotkowski and Marsden 1999). For example, sturgeon eggs are consumed by round gobies (J. Nichols, unpublished data). Furthermore, round gobies are both more numerous and more-effective lake trout egg predators than native predators, such as crayfish (*Orconectes* spp.) and mottled sculpin (Fitzsimons et al. 2003).

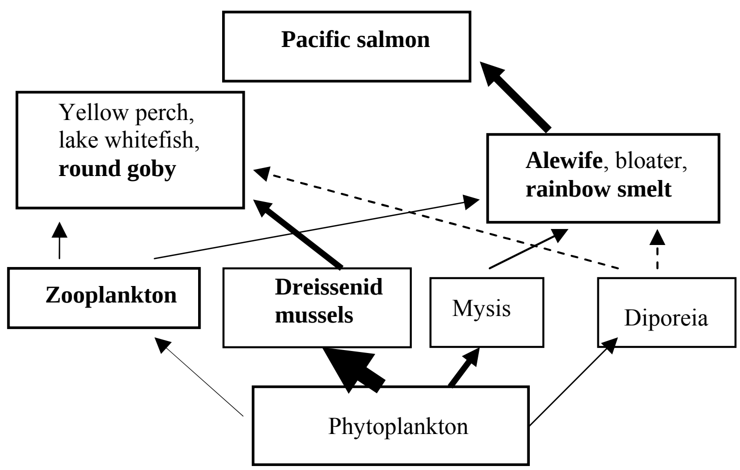
Because dreissenid mussels filter phytoplankton from the water column, they compete directly with zooplankton for food (Fig. 2). Since dreissenid mussels invaded Lake Michigan, zooplankton densities, when first-feeding of yellow perch larvae occurs, have declined by an order of magnitude (Dettmers et al. 2003), indirectly resulting in reduced numbers of age-0 yellow perch in the fall (Clapp and Dettmers 2004).

Fig. 2. Simplified food-web structure of Lake Michigan in 1900 (a) and 2004 (b). Arrows represent the relative energy flow from one group to another, with thicker arrows representing greater energy flow. Dashed lines represent the reduced and declining contribution of *Diporeia* spp. to the trophic level immediately above. Species in **bold** text are invaders or intentionally introduced species that have established themselves in the food web.

a.




b.



The recent decline in *Diporeia* spp. (hereafter, diporeia as a common name) populations in southern Lake Michigan is another apparent indirect effect of dreissenid mussels. Although no specific mechanism for the decline has been demonstrated, diporeia populations did not start declining until zebra mussels were first detected (1989), and, by 1993, diporeia populations declined by over an order of magnitude in parts of the lake (Nalepa et al. 1998). This decline is relevant to the health of nearshore fishes because diporeia is an energy-rich food source and an important prey for several fishes, including alewife, yellow perch, and slimy sculpin (Wells 1980). Alewife condition declined by about 14% after 1995 (Madenjian et al. 2003), suggesting a link between reduced alewife condition and diporeia abundance. More recently, Madenjian et al. (2006) (also see the Status of Planktivore Populations chapter) reexamined the energy density of alewife using bomb calorimetry. Peak energy density of alewife >150 mm in length in the fall declined by 21%, from 9,641 J/g in 1979-1981 (Stewart and Binkowski 1986) to about 7,680 J/g in 2002-2003. In contrast, peak energy density of juvenile alewives, which do not consume diporeia, has remained at about 4,600 J/g. Salmonines must now consume greater numbers of large alewife than they did 30 years ago to achieve the same growth. This constraint may have important repercussions for the entire ecosystem as fishery managers seek optimal levels of predation by salmonines on alewives.

Numerous invasive species have established in Lake Michigan during the last 20 years (Fig. 2), and some of them exert strong impacts on the food web (Jude et al. 2005b). Although some invaders like the spiny water flea have limited discernable impacts, and others like the round goby can have positive impacts, the majority of impacts of invaders appears to be negative. The mechanisms for negative interactions are direct predation, as on lake trout eggs, or competition, as with other nearshore benthic fishes. Indirect interactions of dreissenid mussels, mediated through the food web, have probably negatively affected the recruitment of yellow perch and the condition of alewives. These indirect interactions have the potential for far-ranging impacts on the entire fish community (Fig. 2). Furthermore, after an invader has established itself, fishery managers are largely at the mercy of community interactions to determine if an invader will be a pest. Fishery managers face a very difficult task trying to manage fisheries that are part of an ever-changing set of food-web linkages mediated by invasive species.

Because there is great concern among fishery managers throughout the basin about the potential for new invaders to disrupt the existing community structure, an important emerging need will be tools to (1) predict which species are likely to invade, (2) predict which species are likely to become pests, and (3) especially prevent establishment of those likely to become pests. Without effective prevention measures, including but not limited to (1) eliminating transport by ballast water, (2) preventing planned introductions to other parts of the country that then spread through connecting waterways, and 3) establishing effective rapid-response plans for areas, such as ports and connecting channels, that are potential entry points, the fish community will remain at risk of disruption by invasive species.

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Lake Michigan depicting locations not otherwise identified in this publication. The lake basin is in grey, and treaty-ceded waters are depicted by diagonal lines.

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